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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/955,297	09/19/2001	Carsten Rohr	550-269	8159

23117 7590 09/21/2004

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EXAMINER	
MUTSCHLER, BRIAN L	
ART UNIT	**PAPER NUMBER**
1753	

DATE MAILED: 09/21/2004

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BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

MAILED

SEP 21 2004

GROUP 1700

Application Number: 09/955,297
Filing Date: September 19, 2001
Appellant(s): ROHR ET AL.

Stanley Spooner
For Appellant

EXAMINER'S ANSWER

This is in response to the appeal brief filed July 12, 2004.

(1) Real Party in Interest

A statement identifying the real party in interest is contained in the brief.

(2) Related Appeals and Interferences

A statement identifying the related appeals and interferences which will directly affect or be directly affected by or have a bearing on the decision in the pending appeal is contained in the brief.

(3) Status of Claims

The statement of the status of the claims contained in the brief is incorrect. A correct statement of the status of the claims is as follows:

This appeal involves claims 1-18, 20-27, 31-33, and 35-58.

(4) Status of Amendments After Final

No amendment after final has been filed.

(5) Summary of Invention

The summary of invention contained in the brief is correct.

(6) Issues

The appellant's statement of the issues in the brief is correct.

(7) Grouping of Claims

Appellant's brief includes a statement that claims 1, 18, 33, and 44 do not stand or fall together and provides reasons as set forth in 37 CFR 1.192(c)(7) and (c)(8).

(8) Claims Appealed

The copy of the appealed claims contained in the Appendix to the brief is correct.

(9) Prior Art of Record

Ekins-Daukes et al., "Strain-balanced GaAsP/InGaAs quantum well solar cells," Applied Physics Letters, Vol. 75, No. 26 (27 December 1999), pp. 4195-4197. (Appellant refers to this reference as Ekins-Daukes I.)

5,851,310	Freundlich et al.	12-1998
6,150,604	Freundlich et al.	11-2000

(10) Grounds of Rejection

The following ground(s) of rejection are applicable to the appealed claims:

I. Claims 1-6, 12, 13, 42 and 43 are rejected under 35 U.S.C. 102(b) as being anticipated by Ekins-Daukes et al. ("STRAIN-BALANCED GaAsP/InGaAs QUANTUM WELL SOLAR CELLS", Applied Physics Letters).

Ekins-Daukes et al. disclose a solar cell having strain-balanced quantum wells, wherein the quantum wells contain alternating compressively strained InGaAs quantum wells and tensile strained GaAsP barriers, and "the dimensions were chosen to ensure

the average lattice parameter across the *i* region <*a*> was equal to that of [the GaAs substrate]" (p. 4195). Specifically, Ekins-Daukes et al. teach, "The *i* region was designed as a 20 period cyclic half-barrier/QW/half-barrier structure; each half barrier composed of GaAsP alloy, providing half the strain compensation for the InGaAs QW" (see page 4195). Since each half-barrier structure provides half the strain compensation for the quantum well, the strain over a period comprising two half-barriers and a quantum well would be zero. According to Hooke's Law, the shear strain is directly proportional to shear stress, and the shear stress is equal to the shear force per unit area. Ekins-Daukes et al. disclose that the average strain is a "negligible quantity" based upon the calculation of the average strain as a function of the average lattice constant calculated based on a single quantum well and two half-barriers (p. 4195). Since the shear strain calculated is "a negligible quantity" and the shear force is directly proportional to the shear strain, the shear force would also be a negligible quantity, i.e., each period exerts substantially no shear force on a neighboring structure. It is noted that Appellant does not define the term "substantially" in the phrase "substantially no shear force." Therefore, a negligible amount of shear force is deemed to exert substantially no shear force.

Regarding claim 3, the recitation of the lattice constant of the substrate and the quantum wells inherently describes a crystalline device. A lattice constant is a measure of the distance between adjacent atoms in a regularly spaced arrangement, or crystal structure.

Regarding claims 4 and 5, since the quantum well (or barrier) is made of a material having a specific lattice constant, any quantum well (or barrier) having the same lattice constant as the substrate would necessarily be made of a different material. Since the comparison material is not defined, the material can be chosen from an infinite number of material compositions having an equal lattice constant and differing bandgap.

Regarding claim 6, a period of one quantum well and one barrier layer contains four elements: In, Ga, As and P.

Regarding claims 12 and 13, Ekins-Daukes et al. disclose the use of a GaAs substrate and InGaAs quantum well layers.

Regarding claims 42 and 43, the quantum wells are compressive strained and the barrier layers are tensile strained (see col. 1 on p. 4195).

Since Ekins-Daukes et al. clearly teach the limitations recited in the instant claims, the reference is deemed to be anticipatory.

II. Claims 7-11, 14 and 15 are rejected under 35 U.S.C. 103(a) as being unpatentable over Ekins-Daukes et al. ("STRAIN-BALANCED GaAsP/InGaAs QUANTUM WELL SOLAR CELLS", Applied Physics Letters) in view of Freundlich et al. (U.S. Pat. No. 5,851,310).

Ekins-Daukes et al. disclose a solar cell having the limitations recited in claims 1-6, 12, 13, 42 and 43 of the instant invention, as explained above in section I.

The device of Ekins-Daukes et al. differs from the instant invention because Ekins-Daukes et al. do not disclose the following:

a. The substrate is InP and the compressively strained layer is $In_xGa_{1-x}As$, where x>0.53, as recited in claim 7;

b. The substrate is InP and the tensile strained layer is $In_xGa_{1-x}As_{1-y}P_y$, where y>1, as recited in claim 8;

c. The tensile layer is GaInP, as recited in claim 9;

d. The substrate is InP and the quantum well is formed of layers of $Al_xGa_{1-x}As_ySb_{1-y}$, as recited in claim 10;

e. The substrate is GaSb and the quantum well is formed of layers of $In_xGa_{1-x}As_ySb_{1-y}$, as recited in claim 11;

f. The quantum well portion is formed on a virtual substrate having a virtual substrate lattice constant different from the lattice constant of the substrate, as recited in claim 14; and

g. The virtual substrate is $InP_{1-y}As_y$, where $0<y<1$, and the substrate is InP, as recited in claim 15.

Regarding claims 7-10 and 15, Freundlich et al. disclose a solar cell having an multi-quantum well ("MQW") with an InP substrate (fig. 1). The solar cells use InP because it has a high efficiency (col. 2, lines 30-41).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use an InP

substrate as taught by Freundlich et al. because Freundlich et al. teach that InP cells have a high efficiency.

Regarding claims 7-11, Freundlich et al. disclose that materials usable for fabricating the solar cells include InGaAs and "all alloys of indium gallium arsenide with the addition of iso-valent elements such as phosphorous, aluminum, and antimony in concentrations such that the lattice mismatch is less than 0.3 per cent compared to $In_{0.53}Ga_{0.47}As$" (col. 5, lines 26-39). Freundlich et al. further disclose a specific example using $In_xGa_{1-x}As$, where $0.48<x<0.55$ (col. 5, line 52).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use materials having the compositions taught by Freundlich et al. because Freundlich et al. teach that "these alloys have somewhat different energy bandgaps, which may be desirable in some applications" (col. 5, lines 32-33).

Regarding claim 11, Freundlich et al. disclose that "indium phosphide or other suitable materials well-known in the art may be used as a substrate" (col. 3, lines 58-59).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use other materials to form the substrate as taught by Freundlich et al. because different substrates can provide different desired properties. It is noted that Appellant has

defined the level of one of ordinary skill in the art as having at least "(a) an undergraduate degree in electrical or electronics engineering, (b) at least a masters degree in a related electrical engineering field and (c) at least 5 years experience in the photovoltaic cell field" and that the selection of alternative materials given at least one disclosed substrate material "would be straightforward for a person of ordinary skill in the art" (see Rule 132 Declaration of Dr. Anderson, filed July 23, 2003).

Regarding claim 14, Freundlich et al. disclose the use of buffer layers (virtual substrates) "to accommodate crystal lattice-matching requirements between the sublayer and the top layer of the substrate" (col. 3, lines 58-62).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use a virtual substrate as taught by Freundlich et al. because a virtual substrate helps "accommodate crystal lattice-matching requirements" between the different layers (col. 3, lines 58-62).

Regarding claim 15, Freundlich et al. disclose the use of alloys contained within the indium gallium arsenide series including phosphorous-containing alloys such as InAsP (col. 5, lines 26-39). The buffer layers are chosen to "accommodate crystal lattice-matching requirements" (col. 3, lines 58-62).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use a virtual

substrate of InPAs because Freundlich et al. teach that the solar cell can be made of many different alloys depending on the desired bandgaps and the buffer layer should "accommodate crystal lattice-matching requirements", which would be accomplished by the choice of materials with similar properties.

III. Claims 16 and 17 are rejected under 35 U.S.C. 103(a) as being unpatentable over Ekins-Daukes et al. ("STRAIN-BALANCED GaAsP/InGaAs QUANTUM WELL SOLAR CELLS", Applied Physics Letters) in view of Freundlich et al. (U.S. Pat. No. 6,150,604).

Ekins-Daukes et al. disclose a solar cell having the limitations recited in claims 1-6, 12, 13, 42 and 43 of the instant invention, as explained above in section I.

The device of Ekins-Daukes et al. differs from the instant invention because Ekins-Daukes et al. do not disclose that the device is a thermophotovoltaic device and that the quantum wells have a bandgap equal to or less than 0.73 eV.

Freundlich et al. disclose a MQW thermophotovoltaic solar cell having a bandgap of 0.49-0.74 eV (Table III). The narrow bandgap quantum wells "allows for more efficient conversion of the IR emission emanating from a black body or selective emitter over a wider range of wavelengths than a conventional single junction cell and decreases transparency losses of the conventional cell" (col. 2, lines 40-45).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use narrow bandgap quantum wells as taught by Freundlich et al. because narrow bandgap

quantum wells "allows for more efficient conversion of the IR emission" (col. 2, lines 40-45).

IV. Claims 18 and 20-27 are rejected under 35 U.S.C. 103(a) as being unpatentable over Freundlich et al. (U.S. Pat. No. 5,851,310) in view of Ekins-Daukes et al. ("STRAIN-BALANCED GaAsP/InGaAs QUANTUM WELL SOLAR CELLS", Applied Physics Letters).

Regarding claim 18, Freundlich et al. disclose the use of buffer layers (virtual substrates) "to accommodate crystal lattice-matching requirements between the sublayer and the top layer of the substrate" in MQW solar cells (col. 3, lines 58-62). Freundlich et al. also disclose the use of alloys contained within the indium gallium arsenide series, including phosphorous, aluminum and antimony alloys (col. 5, lines 26-39). The photovoltaic cell is formed on an InP substrate (fig. 1). Freundlich et al. further disclose that the alternating layers in the quantum well portion "are alternately in tensile and compressive strain...[to] reduce the overall strain magnitude in the heterostructure" (col. 7, lines 47-52).

Regarding claims 21 and 22, since the quantum well (or barrier) is made of a material having a specific lattice constant, any quantum well (or barrier) having the same lattice constant as the substrate would necessarily be made of a different material. Since the comparison material is not defined, the material can be chosen from an infinite number of material compositions having an equal lattice constant and differing bandgap.

Regarding claims 23, 25 and 26, the solar cell is formed on an InP substrate and the quantum well portion comprises four elements: In, Ga, As and P (col. 5, lines 28-32). The lattice constant of each period is the same as the adjacent periods (see Table I). In the embodiment comprising an InAsP/InGaP quantum well system, the InGaP is the tensile strained layer (col. 7, lines 54-55).

Regarding claim 27, Freundlich et al. also disclose the use of GaAsSb in the formation of the solar cell (col. 5, lines 26-39).

The device of Freundlich et al. differs from the instant invention because Freundlich et al. do not disclose the following:

a. An InAsP virtual substrate, as recited in claim 18.

b. A period comprising a quantum well layer and a barrier layer exerts no shear stress on a neighboring structure, as recited in claim 18.

c. The neighboring structure is a further period, a layer of arbitrary doping, or the virtual substrate, as recited in claim 20.

d. The compressively strained layer is InGaAs having a larger percentage of indium than the InGaAs composition having the same lattice constant as the virtual substrate, as recited in claim 24.

Regarding the use of an InAsP virtual substrate as recited in claim 18, it would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Freundlich et al. to use a virtual substrate of InPAs because Freundlich et al. teach that the solar cell can be made of many different alloys depending on the desired bandgaps and the buffer layer should "accommodate crystal

lattice-matching requirements", which would be accomplished by the choice of materials with similar properties. As noted above, Appellant has defined the level of one of ordinary skill in the art as having at least "(a) an undergraduate degree in electrical or electronics engineering, (b) at least a masters degree in a related electrical engineering field and (c) at least 5 years experience in the photovoltaic cell field" and that the selection of alternative materials given at least one disclosed substrate material "would be straightforward for a person of ordinary skill in the art" (see Rule 132 Declaration of Dr. Anderson, filed July 23, 2003).

Regarding claims 18 and 20, Ekins-Daukes et al. teach strain-balancing the quantum well layers and the barrier layers in the solar cells so that no strain exists between the layers (p. 4195). This approach allows more quantum wells to be incorporated in the solar cell without causing strain relaxation (p. 4195).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Freundlich et al. to strain-balance the quantum well portion as taught by Ekins-Daukes et al. because balancing the strain within the quantum well portion allows more quantum wells to be used, thus increasing the efficiency of the solar cell.

Regarding claim 24, Ekins-Daukes et al. disclose the use of compressively strained InGaAs layers (p. 4195). Since the layer is compressively strained, the lattice constant is greater than the other layers including the virtual substrate. A layer of

InGaAs with a lattice constant the same as the virtual substrate would have a lower concentration of indium.

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Freundlich et al. to use compressively strained InGaAs layers as taught by Ekins-Daukes et al. because InGaAs quantum wells have been shown by Ekins-Daukes et al. to increase the conversion efficiency of conventional solar cells.

V. Claims 31 and 32 are rejected under 35 U.S.C. 103(a) as being unpatentable over Freundlich et al. (U.S. Pat. No. 5,851,310) in view of Ekins-Daukes et al. ("STRAIN-BALANCED GaAsP/InGaAs QUANTUM WELL SOLAR CELLS", Applied Physics Letters), as applied to claims 18 and 20-27, and further in view of Freundlich et al. (U.S. Pat. No. 6,150,604).

In US '310, Freundlich et al. and Ekins-Daukes et al. describe a solar cell having the limitations recited in claims 18 and 20-27 of the instant invention, as explained above in section IV.

The device described by Freundlich et al. (US '310) and Ekins-Daukes et al. differs from the instant invention because they do not disclose the following:

a. The device is a thermophotovoltaic device, as recited in claim 31.

b. The quantum wells have a bandgap of 0.73 eV or less, as recited in claims 32.

Regarding claims 31 and 32, Freundlich et al. (US '604) disclose a MQW thermophotovoltaic solar cell having a bandgap of 0.49-0.74 eV (Table III). The narrow bandgap quantum wells "allows for more efficient conversion of the IR emission emanating from a black body or selective emitter over a wider range of wavelengths than a conventional single junction cell and decreases transparency losses of the conventional cell" (col. 2, lines 40-45).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device described by Freundlich et al. (US '310) and Ekins-Daukes et al. to use narrow bandgap quantum wells as taught by Freundlich et al. (US '604) because narrow bandgap quantum wells "allows for more efficient conversion of the IR emission" (col. 2, lines 40-45).

VI. Claims 33 and 35-41 are rejected under 35 U.S.C. 103(a) as being unpatentable over Freundlich et al. (U.S. Pat. No. 5,851,310) in view of Ekins-Daukes et al. ("STRAIN-BALANCED GaAsP/InGaAs QUANTUM WELL SOLAR CELLS", Applied Physics Letters) and in view of Freundlich et al. (U.S. Pat. No. 6,150,604).

Regarding claim 33, Freundlich et al. (US '310) disclose the use of alloys contained within the indium gallium arsenide series, including phosphorous, aluminum and antimony alloys (col. 5, lines 26-39). The photovoltaic cell is formed on an InP substrate (fig. 1). In one embodiment, Freundlich et al. disclose an InAsP/InGaP quantum well system, the InGaP is the tensile strained layer (col. 7, lines 54-55).

Freundlich et al. also disclose the use of $In_xGa_{1-x}As$ where x can be larger than 0.53 (col. 5, lines 52-54).

Regarding claim 38, Freundlich et al. disclose the use of buffer layers (virtual substrates) "to accommodate crystal lattice-matching requirements between the sublayer and the top layer of the substrate" in MQW solar cells (col. 3, lines 58-62).

The device of Freundlich et al. (US '310) differs from the instant invention because Freundlich et al. do not disclose the following:

a. The quantum well is comprised of alternating layers of $In_xGa_{1-x}As$, where $x>0.53$, and barrier layers of $Ga_yIn_{1-y}P$, where $y>0$, as recited in claim 33

b. A period of one tensile strained layer and one compressively strained layer exerts no shear force on a neighboring structure, as recited in claim 33.

c. The neighboring structure is a further period, a layer of arbitrary doping, or a substrate, as recited in claim 35.

d. The device is a thermophotovoltaic device, as recited in claim 40.

e. The quantum wells have a bandgap of 0.73 eV or less, as recited in claim 41.

f. The virtual substrate is InPAs, as recited in claim 39.

Regarding claim 33, Freundlich et al. (US '604) disclose the use of InGaAs wells under compressive strain, with a specific example of wells comprising $In_{0.9}Ga_{0.1}As$ (col. 5, line 9).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Freundlich et al. (US '310) to use a compressively strained InGaAs layer having a high indium concentration as taught by Freundlich et al. (US '604) because an InGaAs layer with a high indium concentration has a narrower bandgap, which increases the absorption of the IR regions.

Regarding claims 33 and 35, Ekins-Daukes et al. teach strain-balancing the quantum well layers and the barrier layers in the solar cells so that no strain exists between the layers (p. 4195). This approach allows more quantum wells to be incorporated in the solar cell without causing strain relaxation (p. 4195).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Freundlich et al. to strain-balance the quantum well portion as taught by Ekins-Daukes et al. because balancing the strain within the quantum well portion allows more quantum wells to be used, thus increasing the efficiency of the solar cell.

Regarding claim 39, it would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Freundlich et al. to use a virtual substrate of InPAs because Freundlich et al. teach that the solar cell can be made of many different alloys depending on the desired bandgaps and the buffer layer should "accommodate crystal lattice-matching requirements", which would be accomplished by the choice of materials with similar properties. As noted above,

Appellant has defined the level of one of ordinary skill in the art as having at least "(a) an undergraduate degree in electrical or electronics engineering, (b) at least a masters degree in a related electrical engineering field and (c) at least 5 years experience in the photovoltaic cell field" and that the selection of alternative materials given at least one disclosed substrate material "would be straightforward for a person of ordinary skill in the art" (see Rule 132 Declaration of Dr. Anderson, filed July 23, 2003).

Regarding claims 40 and 41, Freundlich et al. (US '604) disclose a MQW thermophotovoltaic solar cell having a bandgap of 0.49-0.74 eV (Table III). The narrow bandgap quantum wells "allows for more efficient conversion of the IR emission emanating from a black body or selective emitter over a wider range of wavelengths than a conventional single junction cell and decreases transparency losses of the conventional cell" (col. 2, lines 40-45).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Freundlich et al. (US '310) to use narrow bandgap quantum wells as taught by Freundlich et al. (US '604) because narrow bandgap quantum wells "allows for more efficient conversion of the IR emission" (col. 2, lines 40-45).

VII. Claims 44-47, 53 and 54 are rejected under 35 U.S.C. 103(a) as being unpatentable over Ekins-Daukes et al. ("STRAIN-BALANCED GaAsP/InGaAs QUANTUM WELL SOLAR CELLS", Applied Physics Letters).

Ekins-Daukes et al. disclose a solar cell having strain-balanced quantum wells, wherein the quantum wells contain alternating compressively strained InGaAs quantum wells and tensile strained GaAsP barriers, and "the dimensions were chosen to ensure the average lattice parameter across the *i* region <*a*> was equal to that of [the GaAs substrate]" (p. 4195). Specifically, Ekins-Daukes et al. teach, "The *i* region was designed as a 20 period cyclic half-barrier/QW/half-barrier structure; each half barrier composed of GaAsP alloy, providing half the strain compensation for the InGaAs QW" (see page 4195). Since each half-barrier structure provides half the strain compensation for the quantum well, the strain over a period comprising two half-barriers and a quantum well would be zero. According to Hooke's Law, the shear strain is directly proportional to shear stress, and the shear stress is equal to the shear force per unit area. Ekins-Daukes et al. disclose that the average strain is a "negligible quantity" based upon the calculation of the average strain as a function of the average lattice constant calculated based on the thickness and material properties (i.e., lattice constant) a single quantum well and two half-barriers (p. 4195). Since the shear strain calculated is "a negligible quantity" and the shear force is directly proportional to the shear strain, the shear force would also be a negligible quantity, i.e., each period exerts substantially no shear force on a neighboring structure. It is noted that Appellant does not define the term "substantially" in the phrase "substantially no shear force." Therefore, a negligible amount of shear force is deemed to exert substantially no shear force.

Regarding claims 45 and 46, since the quantum well (or barrier) is made of a material having a specific lattice constant, any quantum well (or barrier) having the same lattice constant as the substrate would necessarily be made of a different material. Since the comparison material is not defined, the material can be chosen from an infinite number of material compositions having an equal lattice constant and differing bandgap.

Regarding claim 47, a period of one quantum well and one barrier layer contains four elements: In, Ga, As and P.

Regarding claims 53 and 54, Ekins-Daukes et al. disclose the use of a GaAs substrate and InGaAs quantum well layers.

The photovoltaic device of Ekins-Daukes et al. differs from the instant invention because Ekins-Daukes et al. do not disclose equations recited in the claims, especially in regard to the elastic stiffness coefficient, as recited in claim 44.

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have made the photovoltaic device from tensile strained layers and compressively strained layers having a composition substantially meeting the conditions defined by the equations recited in the instant claims because one of ordinary skill in the art would have recognized that the elastic stiffness coefficient influences the strain within the layers and therefore would have been encompassed by the teachings of Ekins-Daukes et al., who clearly desire that each barrier compensates for the strain of the adjacent quantum well. In order to meet those conditions, the materials used to form the compressively strained layers and tensile strained layers

must inherently have the properties that satisfy the equations recited in the claims because in order to satisfy the zero stress condition (the first equation recited in claim 44), the strain must also substantially equal zero. This is a result of Hooke's Law, which states that the shear strain is directly proportional to the shear stress. The person of ordinary skill in the art, who is "a highly skilled and experienced individual" (see page 23 of Appellant's response filed July 23, 2003), would recognize the relationship between the different material properties, such as lattice constant and elastic stiffness coefficient, and their influences on the strain between adjacent layers. As can be seen in the equations recited in the claims and the teachings of Ekins-Daukes et al., the final result is the same; each full barrier (i.e., two half-barriers) provides the strain compensation of the adjacent quantum well.

VIII. Claims 48-52, 55 and 56 are rejected under 35 U.S.C. 103(a) as being unpatentable over Ekins-Daukes et al. ("STRAIN-BALANCED GaAsP/InGaAs QUANTUM WELL SOLAR CELLS", Applied Physics Letters), as applied above to claims 44-47, 53 and 54, in view of Freundlich et al. (U.S. Pat. No. 5,851,310).

Ekins-Daukes et al. teach the limitations recited in claims 44-47, 53 and 54 of the instant invention, as explained above in section VII.

The device of Ekins-Daukes et al. differs from the instant invention because Ekins-Daukes et al. do not disclose the following:

a. The substrate is InP and the compressively strained layer is $In_xGa_{1-x}As$, where $x>0.53$, as recited in claim 48;

b. The substrate is InP and the tensile strained layer is $In_xGa_{1-x}As_{1-y}P_y$, where y>1, as recited in claim 49;

c. The tensile layer is GaInP, as recited in claim 50;

d. The substrate is InP and the quantum well is formed of layers of $Al_xGa_{1-x}As_ySb_{1-y}$, as recited in claim 51;

e. The substrate is GaSb and the quantum well is formed of layers of $In_xGa_{1-x}As_ySb_{1-y}$, as recited in claim 52;

f. The quantum well portion is formed on a virtual substrate having a virtual substrate lattice constant different from the lattice constant of the substrate, as recited in claim 55; and

g. The virtual substrate is $InP_{1-y}As_y$, where 0<y<1, and the substrate is InP, as recited in claim 56.

Regarding claims 48-51 and 56, Freundlich et al. disclose a solar cell having an MQW with an InP substrate (fig. 1). The solar cells use InP because it has a high efficiency (col. 2, lines 30-41).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use an InP substrate as taught by Freundlich et al. because Freundlich teaches that InP cells have a high efficiency.

Regarding claims 48-52, Freundlich et al. disclose that materials usable for fabricating the solar cells include InGaAs and "all alloys of indium gallium arsenide with

the addition of iso-valent elements such as phosphorous, aluminum, and antimony in concentrations such that the lattice mismatch is less than 0.3 per cent compared to $In_{0.53}Ga_{0.47}As$" (col. 5, lines 26-39). Freundlich et al. further disclose a specific example using $In_xGa_{1-x}As$, where $0.48<x<0.55$ (col. 5, line 52).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use materials having the compositions taught by Freundlich et al. because Freundlich et al. teach that "these alloys have somewhat different energy bandgaps, which may be desirable in some applications" (col. 5, lines 32-33).

Regarding claim 48, Freundlich et al. disclose that "indium phosphide or other suitable materials well-known in the art may be used as a substrate" (col. 3, lines 58-59).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use other materials to form the substrate as taught by Freundlich et al. because different substrates can provide different desired properties. As noted above, Appellant has defined the level of one of ordinary skill in the art as having at least "(a) an undergraduate degree in electrical or electronics engineering, (b) at least a masters degree in a related electrical engineering field and (c) at least 5 years experience in the photovoltaic cell field" and that the selection of alternative materials given at least one

disclosed substrate material "would be straightforward for a person of ordinary skill in the art" (see Rule 132 Declaration of Dr. Anderson, filed July 23, 2003).

Regarding claim 55, Freundlich et al. disclose the use of buffer layers (virtual substrates) "to accommodate crystal lattice-matching requirements between the sublayer and the top layer of the substrate" (col. 3, lines 58-62).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use a virtual substrate as taught by Freundlich et al. because a virtual substrate helps "accommodate crystal lattice-matching requirements" between the different layers (col. 3, lines 58-62).

Regarding claim 56, Freundlich et al. disclose the use of alloys contained within the indium gallium arsenide series including phosphorous-containing alloys such as InAsP (col. 5, lines 26-39). The buffer layers are chosen to "accommodate crystal lattice-matching requirements" (col. 3, lines 58-62).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use a virtual substrate of InPAs because Freundlich et al. teach that the solar cell can be made of many different alloys depending on the desired bandgaps and the buffer layer should "accommodate crystal lattice-matching requirements", which would be accomplished by the choice of materials with similar properties.

IX. Claims 57 and 58 are rejected under 35 U.S.C. 103(a) as being unpatentable over Ekins-Daukes et al. ("STRAIN-BALANCED GaAsP/InGaAs QUANTUM WELL SOLAR CELLS", Applied Physics Letters), as applied above to claims 44-47, 53 and 54, in view of Freundlich et al. (U.S. Pat. No. 6,150,604).

Ekins-Daukes et al. teach the limitations recited in claims 44-47, 53 and 54 of the instant invention, as explained above in section VII.

The device of Ekins-Daukes et al. differs from the instant invention because Ekins-Daukes et al. do not disclose that the device is a thermophotovoltaic device and that the quantum wells have a bandgap equal to or less than 0.73 eV.

Freundlich et al. disclose a MQW thermophotovoltaic solar cell having a bandgap of 0.49-0.74 eV (Table III). The narrow bandgap quantum wells "allows for more efficient conversion of the IR emission emanating from a black body or selective emitter over a wider range of wavelengths than a conventional single junction cell and decreases transparency losses of the conventional cell" (col. 2, lines 40-45).

It would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the device of Ekins-Daukes et al. to use narrow bandgap quantum wells as taught by Freundlich et al. because narrow bandgap quantum wells "allows for more efficient conversion of the IR emission" (col. 2, lines 40-45).

(11) Response to Argument

1. Discussion of the References

It is noted that Appellant addresses each reference individually even though the Freundlich et al. patents have only been used in combination with the Ekins-Daukes et al. reference.

Ekins-Daukes et al.

Appellant argues that "Ekins-Daukes teaches that it is only necessary that <u>the average strain</u> for all quantum wells and barriers be adjusted to the substrate and provides formulas in which values can be chosen so as to minimize the average strain" and that "[t]here is no recognition in Ekins-Daukes that the overall average strain is not as important as the strain of each period" (see page 6 of Appeal Brief).

Ekins-Daukes et al. teach that "each half-barrier [is] composed of GaAsP alloy, providing half the strain compensation for the InGaAs QW" (p. 4195). Ekins-Daukes et al. further calculate the average strain of two half-barriers and one quantum well based on the thicknesses and lattice constants of the materials, choosing values to minimize the average strain (p. 4195). This average strain is a "negligible quantity" (p. 4195). Since shear strain is directly proportional to shear force and each half-barrier provides half the strain compensation for each quantum well, the negligible quantity of shear strain results in a negligible quantity of shear force. This negligible quantity of shear force is deemed sufficient to anticipate the "substantially no shear force" claimed by Appellant. It is noted that Appellant has not defined "substantially no shear force" in the original disclosure.

Freundlich et al. '310 (U.S. Pat. No. 5,851,310)

Appellant argues that "[t]here is no disclosure in Freundlich '310 that there is any benefit to choosing quantum wells and barriers such that a period of one tensile strained layer and one compressively strained layer exerts substantially no shear force on a neighboring structure" (see page 7 of Appeal Brief).

The Examiner admits that Freundlich et al. (US '310) do not teach that each period of a barrier and a quantum well exerts substantially no shear force on a neighboring structure. Freundlich et al. do teach, "The total critical thickness of the quantum well region can be increased by alternating layers that...are alternately in tensile and compressive strain[, and t]his technique will reduce the overall strain magnitude in the heterostructure" (US '310 at col. 7, lines 45-52). Therefore, Freundlich et al. acknowledge the desire to reduce strain by alternating compressive strained and tensile strained layers, which is consistent with the teachings of Ekins-Daukes et al., who teach the use of strain-balanced quantum wells having alternating compressive and tensile strained layers.

Freundlich et al. '604 (U.S. Pat. No. 6,150,604)

Appellant applies the same argument to Freundlich et al. (US '604) as that used above to address Freundlich et al. (US '310).

As discussed above, Freundlich et al. is used only in combination with the teachings of Ekins-Daukes et al., who teach the use of strain-balanced quantum wells having alternating compressive and tensile strained layers.

2. *Discussion of the Rejections*

Regarding the rejection of claims 1-6, 12, 13, 42, and 43 under 35 U.S.C. 102(b) over Ekins-Daukes et al., Appellant argues that "the Examiner failed to point to any disclosure in the Ekins-Daukes I reference which suggests that [each period exerts substantially no shear force on a neighboring structure] or would teach one of ordinary skill in the art how to accomplish this result" (see pages 7-8 of Appeal Brief).

As explained above in the rejection of the claims, Ekins-Daukes et al. teach that "each half barrier [is] composed of GaAsP alloy, providing half the strain compensation for the InGaAs QW" (see page 4195). Since each half-barrier structure provides half the strain compensation for the quantum well, the strain over a period comprising two half-barriers and a quantum well would be zero. According to Hooke's Law, the shear strain is directly proportional to shear stress, and the shear stress is equal to the shear force per unit area. Ekins-Daukes et al. disclose that the average strain is a "negligible quantity" based upon the calculation of the average strain as a function of the average lattice constant calculated based on the thickness and material properties (i.e., lattice constant) a single quantum well and two half-barriers (p. 4195). Since the shear strain calculated is "a negligible quantity" and the shear force is directly proportional to the

shear strain, the shear force would also be a negligible quantity, i.e., each period exerts substantially no shear force on a neighboring structure.

It is noted that in Appellant's response filed November 26, 2003, Appellant states the following:

> Ekins-Daukes I teaches the desirability of compositions such that the adjacent layers exert substantially no shear force on a neighboring structure. The desirability of this end result is clear from the Ekins-Daukes I reference. (See page 15 of Appellant's response filed November 26, 2003.)

Ekins-Daukes et al. teach that thicknesses are chosen "to minimize the average strain" (p. 4195). Therefore, the reference is deemed to be anticipatory.

Regarding the rejection of claims 7-11, 14, and 15 under 35 U.S.C. 103 over Ekins-Daukes et al. in view of Freundlich et al. (US '310), Appellant argues that there is "no disclosure...as to where or how one of ordinary skill in the art would be motivated to combine these two references or even if they could be combined" (see page 8 of Appeal Brief).

As explained in the Final Rejection and above, one of ordinary skill in the art would have been motivated to combine the references because Freundlich et al. (US '310) teaches that different materials provide different desirable properties, such as different energy bandgaps. For example, narrow bandgaps provide for more efficient absorption in the infrared range. It is further noted that Appellant has defined the level of ordinary skill in the art as a highly skilled person, and that the substitution of materials is "straightforward" (see Rule 132 Declaration filed July 23, 2003).

Furthermore, the disclosures of Ekins-Daukes et al. and Freundlich et al. (US '310) are related to the same field of endeavor and both references appreciate the desire to minimize the strain in quantum well solar cells.

Regarding the rejection of claims 16 and 17 under 35 U.S.C. 103 over Ekins-Daukes et al. in view of Freundlich et al. (US '604), Appellant argues that "the reasons for combining these references is not apparent to the reader of the Final Rejection" (see page 9 of Appeal Brief).

As explained above and in the Final Rejection, Freundlich et al. (US '604) teaches that narrow bandgap materials "allow for more efficient conversion of the IR emission" (US '604 at col. 2, lines 40-45). Therefore, using such materials would allow for more efficient conversion in the IR range.

Regarding the rejection of claims 18 and 20-27 under 35 U.S.C. 103 over Freundlich et al. (US '310) in view of Ekins-Daukes et al., Appellant argues that "the Examiner has not provided any indication of how the theoretical benefit of Ekins-Daukes I is to be achieved or why there would be any reason to combine Ekins-Daukes I with the Freundlich '310 disclosure" (see page 9 of Appeal Brief).

As explained above, Ekins-Daukes et al. teach that the "theoretical benefit" is achieved by using half-barriers that provide half the strain compensation of the quantum wells and choosing values that minimize the average strain (p. 4195).

The references are related to the same field of endeavor. Furthermore, both Ekins-Daukes et al. and Freundlich et al. (US '310) teach the desirability of minimizing strain using alternating tensile strained and compressively strained layers. Ekins-Daukes et al. further teach that strain-balancing the layers enhances the efficiency of the photovoltaic cells. Therefore, it would have been obvious to one having ordinary skill in the art at the time the invention was made to have combined the references of Freundlich et al. (US '310) and Ekins-Daukes et al. because Ekins-Daukes et al. teach how to solve the problem identified by Freundlich et al.

Regarding the rejection of claims 31 and 32 under 35 U.S.C. 103 over Freundlich et al. (US '310) in view of Ekins-Daukes et al. and further in view of Freundlich et al. (US '604), Appellant argues that "[t]here is no apparent motivation for such combination discussed in the Official Action" (see page 10 of Appeal Brief).

As explained above and in the Final Rejection, it would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the bandgap of the device described by Freundlich et al. (US '310) and Ekins-Daukes et al. to use a material with a bandgap of 0.73 eV or less because Freundlich et al. (US '604) teaches that narrow bandgap quantum wells (i.e., 0.49-0.7 eV) allow for more efficient conversion of the IR emission. It is further noted that the '604 patent is a continuation-in-part of the '310 patent.

Regarding the rejection of claims 33 ad 35-41 under 35 U.S.C. 103 over Freundlich et al. (US '310) in view of Ekins-Daukes et al. and Freundlich et al. (US '604), Appellant argues that "there appears to be no motivation for such combination suggested in the Official Action" (see page 10 of Appeal Brief).

As explained above, each of the references is in the field of multi-quantum well photovoltaic cells, and each reference teaches the desirability of minimizing the strain within the structure. Ekins-Daukes et al. provides motivation for strain-balancing the quantum wells and barriers and Freundlich et al. (US '604) provides motivation for the choice of materials, namely to increase the efficiency of the device. Please see rejection above, which corresponds to the rejection set forth in the Final Rejection.

Regarding the rejection of claims 44-47, 53, and 54 under 35 U.S.C. 103 over Ekins-Daukes et al., Appellant argues that while Ekins-Daukes et al. teach that "the average strain is negligible and that the strain across one period is a function of the thickness in material properties of each layer..., Ekins-Daukes I does not suggest how to ensure that the strain in each period exerts substantially no shear force on a neighboring structure" (see page 10 of Appeal Brief).

As explained above, Ekins-Daukes et al. teach that the strain can be minimized by choosing the thickness of the layers and that "each half barrier...[provides] half the strain compensation for the...QW" (p. 4195). Since the strain is directly proportional to the shear force, a negligible quantity of strain provides a negligible quantity of shear

force. Therefore, one skilled in the art would be motivated to choose compositions that provide a negligent amount of strain, and consequently, substantially no shear force.

Regarding the rejection of claims 48-52, 55, and 56 under 35 U.S.C. 103 over Ekins-Daukes et al. in view of Freundlich et al. (US '310), Appellant again argues that "there is no disclosure as to how or why one of ordinary skill in the art would be motivated to combine elements from the various references" (see page 11 of Appeal Brief).

As explained above, one skilled in the art would be motivated to combine elements from the references because Freundlich et al. (US '310) teaches that materials such as InP have a high efficiency. Furthermore, Freundlich et al. (US '310) teach that different alloys have different energy bandgaps, which is desirable in certain applications. As indicated above, Appellant has defined one of ordinary skill in the art as a person who deems the choice alternative materials as "straightforward" (see Rule 132 Declaration filed July 23, 2003).

Regarding the rejection of claims 57 and 58 under 35 U.S.C. 103 over Ekins-Daukes et al. in view of Freundlich et al. (US '604), Appellant argues that there is no indications as to "how or why one of ordinary skill in the art would be motivated to combine the Ekins-Daukes and Freundlich '604 references" (see page 11 of Appeal Brief).

As explained above and in the Final Rejection, it would have been obvious to one having ordinary skill in the art at the time the invention was made to have modified the bandgap of the device described by Ekins-Daukes et al. to use a material with a bandgap of 0.73 eV or less because Freundlich et al. (US '604) teaches that narrow bandgap quantum wells (i.e., 0.49-0.7 eV) allow for more efficient conversion of the IR emission.

3. The Errors in the Final Rejection

Appellant contends that there are at least four significant errors in the Final Rejection.

(a) No prior art reference teaches that in order to create an efficient photovoltaic device, it is necessary that the composition of the strained layers be such that each period "exerts substantially no shear force on a neighboring structure"

Appellant argues that "The Freundlich '310 and '604 references, as admitted by the Examiner, do not teach any sort of strain balancing construction" (see page 12 of Appeal Brief).

The Examiner respectfully disagrees with this statement because, as explained both above and in the Final Rejection, US '310 teaches, "The total critical thickness of the quantum well region can be increased by alternating layers that...are alternately in

tensile and compressive strain[, and t]his technique will reduce the overall strain magnitude in the heterostructure" (US '310 at col. 7, lines 45-52). Therefore, Freundlich et al. teach the desirability of a strain balancing construction.

Appellant further argues that "while Ekins-Daukes I recognizes that it is desirable to reduce the strain to a negligible quantity, there is no teaching that this can be done by ensuring that each period exerts 'substantially no shear force on a neighboring structure'" (see page 13 of Appeal Brief).

Ekins-Daukes et al. clearly teach that "each half barrier [is] composed of GaAsP alloy, providing half the strain compensation for the InGaAs QW" (p. 4195). It is further taught that the thicknesses are chosen to minimize the average strain, which is calculated based on the thicknesses of two half-barriers and a quantum well (p. 4195). Furthermore, the strain is disclosed as being a "negligible quantity" (p. 4195). Since shear force is directly proportional to strain, a negligible quantity of strain provides a negligible shear force. Since Appellant has not defined what constitutes "substantially no shear force," the Examiner deems a negligible shear force to be substantially no shear force.

Appellant further provides an "example" taught by Ekins-Daukes et al., wherein one period has a strain of +4 and an adjacent period has a strain of -4 (see page 13 of Appeal Brief).

First, contrary to Appellant's assertion that "the above example [is] taught in the Ekins-Daukes I reference," Ekins-Daukes et al. do not provide any such "example." Nowhere in the Ekins-Daukes et al. reference does such an example appear.

Second, while Appellant's "example" yields an average strain of zero, the Examiner does not believe that such and "example" is consistent with the teachings of Ekins-Daukes et al. Ekins-Daukes et al. clearly teach that "each half barrier [is] composed of GaAsP alloy, providing half the strain compensation for the InGaAs QW" (p. 4195). It is further taught that the thicknesses are chosen to minimize the average strain, which is calculated based on the thicknesses of two half-barriers and a quantum well (p. 4195). Furthermore, the strain is disclosed as being a "negligible quantity" (p. 4195). Therefore, because the strain is calculated based on a single period of two half-barriers and one quantum well, the clearest teaching of Ekins-Daukes et al. provides that each period is strain-balanced, not just the entire quantum well portion.

Appellant further argues that "the Examiner has either failed to understand or appreciate this claim requirement [i.e., that each period exerts substantially no shear force on a neighboring structure] or has ignored it in each Office Action" (see page 14 of Appeal Brief).

As explained above and in each Office Action, Ekins-Daukes et al. teaches that "each half barrier [is] composed of GaAsP alloy, providing half the strain compensation for the InGaAs QW" (p. 4195). It is further taught that the thicknesses are chosen to minimize the average strain, which is calculated based on the thicknesses of two half-

barriers and a quantum well (p. 4195). Furthermore, the strain is disclosed as being a "negligible quantity" (p. 4195). Therefore, because the strain is calculated based on a single period of two half-barriers and one quantum well, the clearest teaching of Ekins-Daukes et al. provides that each period is strain-balanced, not just the entire quantum well portion.

(b) Ekins-Daukes I teaches that the average for <u>all</u> periods must be minimized, but not that <u>each</u> period should exert "substantially no shear force on a neighboring structure"

Appellant argues, "Not only does the Ekins-Daukes I reference fail to teach that it is desirable that each period 'exerts substantially no shear force on a neighboring structure,' but in teaching that it is only necessary that the average lattice parameter across the entire 20-period layer be a negligible quantity, Ekins-Daukes essentially suggests that one can ignore shear forces created by individual periods and need only tailor the average shear force of the entire 20-period cycle" (see pages 15-16 of Appeal Brief).

As explained above and in the Final Rejection, Ekins-Daukes et al. teaches that "each half barrier [is] composed of GaAsP alloy, providing half the strain compensation for the InGaAs QW" (p. 4195). It is further taught that the thicknesses are chosen to minimize the average strain, which is calculated based on the thicknesses of two half-barriers and a quantum well (p. 4195). Furthermore, the strain is disclosed as being a

"negligible quantity" (p. 4195). Therefore, because the strain is calculated based on a single period of two half-barriers and one quantum well, the clearest teaching of Ekins-Daukes et al. provides that each period is strain-balanced, not just the entire quantum well portion.

Additionally, Ekins-Daukes et al. do not appear to teach that "one can ignore shear forces created by individual periods" as argued by Appellant. As explained above, Ekins-Daukes et al. teach that each period should be strain-balanced by providing that each half-barrier provides half the strain compensation for each quantum well, i.e., each full barrier provides the full strain compensation for the quantum well.

(c) Freundlich '310 and '604, in suggesting limiting to 20 periods, teach away from the claimed invention

Appellant argues that the Freundlich et al. references teach away from the claimed invention because they suggest limiting the number of periods to 20 or less.

First, the Examiner disagrees with this argument because Appellant has not claimed more than 20 periods. The claims recite "a plurality of quantum wells" and "a plurality of barriers." Twenty periods clearly comprises a plurality of each layer.

Second, in US '310, Freundlich et al. teach, "The total critical thickness of the quantum well region can be increased by alternating layers that...are alternately in tensile and compressive strain[, and t]his technique will reduce the overall strain

magnitude in the heterostructure" (US '310 at col. 7, lines 45-52). Using this technique, Freundlich et al. disclose the formation of a photovoltaic cell comprising 30 periods.

(d) There is no reason or motivation for combining any of the prior art references

Appellant repeats the arguments addressed above regarding the general motivation to combine the references. In addition, Appellant argues that "because these references teach two different solutions to the problem, their combination would involve utilizing less than 20 periods and ensuring that the average 'strain-balance' for the 20 periods was a negligible quantity" (see page 18 of Appeal Brief).

Appellant's arguments regarding the general motivation to combine the references has been addressed above in the Office Actions in detail. Regarding Appellant's argument that "the references teach two different solutions to the problem," it is noted that Ekins-Daukes et al. and Freundlich et al. (US '310) reach similar conclusions to deal with the problem. In both references, tensile strained layers are alternated with compressively strained layers to minimize the overall strain magnitude. Ekins-Daukes et al. further teach the use of barrier layers that provide the strain compensation of the quantum wells (see p. 4195). Therefore, the references are related to solving a common problem and identify similar solutions to that problem.

For the above reasons, it is believed that the rejections should be sustained.

Respectfully submitted,

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September 8, 2004

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